PHILOSOPHICAL TRANSACTIONS.

I. *On Calorescence. By Professor* J. TYNDALL, *LL.D. Camb., F.R.S., Member of the Academies and Societies of Holland, Geneva, Göttingen, Zürich, Halle, Marburg, Breslau, Upsala, Cherbourg, la Société Philomathique of Paris, Cam. Phil. Soc. &c.; Professor of Natural Philosophy in the Royal Institution and the Royal School of Mines.*

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Forsitan et roseâ sol altè lampade lucens
Possideat multum cæcis fervoribus ignem
Circum se, nullo qui sit fulgore notatus,
Æstiferum ut tantum radiorum exaugeat ictum.
LUCRET. v. 610*.

§ 1.

IN the year 1800, and in the same volume of the Philosophical Transactions that contains VOLTA'S celebrated letter to Sir JOSEPH BANKS on the Electricity of Contact†, Sir WILLIAM HERSCHEL published his discovery of the invisible rays of the sun. Causing thermometers to pass through the various colours of the solar spectrum, he determined their heating-power, and found that this power, so far from ending at the red extremity of the spectrum, rose to a maximum at some distance beyond the red. The experiment proved that, besides its luminous rays, the sun emitted others of low refrangibility, which possessed great calorific power, but were incompetent to excite vision.

Drawing a datum-line to represent the length of the spectrum, and erecting at various points of this line perpendiculars to represent the calorific intensity existing at those points, on uniting the ends of the perpendiculars Sir WILLIAM HERSCHEL obtained the subjoined curve (fig. 1), which shows the distribution of heat in the solar spectrum, according to his observations. The space A B D represents the invisible, and B D E the visible radiation of the sun. With the more perfect apparatus subsequently devised, Professor MÜLLER of Freiburg examined the distribution of heat in the spectrum‡,

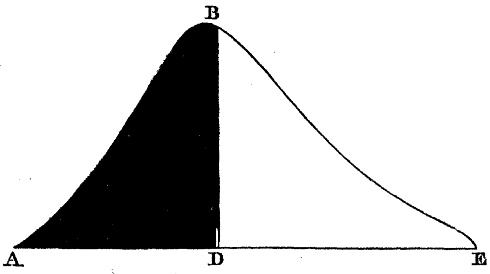
* I am indebted to my excellent friend Sir EDMUND HEAD for this extract, which reads like divination.

† Vol. lxx.

‡ Philosophical Magazine, Ser. 4. vol. xvii. p. 242.

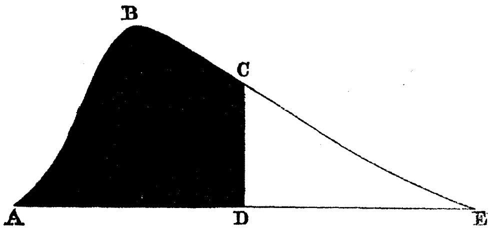
and the results of his observations are rendered graphically in fig. 2. Here the area A B C D represents the invisible, while C D E represents the visible radiation.

Fig. 1.



Spectrum of Sun (Herschel) reduced.

Fig. 2.



Spectrum of Sun (Müller).

With regard to terrestrial sources of heat, it may be stated that all such sources hitherto examined emit those obscure rays. MELLONI found that 90 per cent. of the emission from an oil-flame, 98 per cent. of the emission from incandescent platinum, and 99 per cent. of the emission from an alcohol-flame consists of obscure rays*. The visible radiation from a hydrogen-flame is, according to my own experiments, too small to admit of measurement. With regard to solid bodies, it may be stated generally that, when they are raised from a state of obscurity to vivid incandescence, the invisible rays emitted in the first instance continue to be emitted with augmented power when the body glows. For example, with a current of feeble power the carbons of the electric lamp may be warmed and caused to emit invisible rays. But the intensity of these same rays may be augmented a thousandfold by raising the carbons to the temperature necessary for the electric light. Here, in fact, the luminous and non-luminous emission augment together, the maximum of brightness of the visible rays occurring simultaneously with the maximum calorific power of the invisible ones†.

At frequent intervals during the past ten or twelve years I have had occasion to experiment on the invisible rays of the electric light, and have finally made them the subject of special investigation. The present paper contains a brief account of the inquiry. I endeavour, in the first place, to compare the luminous with the non-luminous radiation of the electric light, and to determine their relative energy; I point out a method of detaching the luminous from the non-luminous rays; and afterwards describe various experiments illustrative of the calorific power of the invisible rays, and of the transmutations of which they are capable.

§ 2.

The instrument employed by Professor MÜLLER in the investigation above alluded to, was a form of the thermo-electric pile devised by MELLONI for the examination of this and kindred questions. Through the kindness of my friend Mr. GASSIOT, a very beautiful instrument of this kind, constructed by RUHMKORFF, has remained in my possession for several years, and been frequently employed in my researches. It consists of a double metallic screen, with a rectangular aperture in the centre—a single row of thermo-electric

* La Thermochrose, p. 304.

† On this point see the Rede Lecture for 1865, p. 33 (Longmans).

elements 1·2 inch in length being fixed to the screen behind the aperture. Connected with the latter are two moveable side pieces, which can be caused to approach or recede so as to vary the width of the exposed face of the pile from zero to $\frac{1}{10}$th of an inch. The instrument is mounted on a slider, which, by turning a handle, is moved along a slot on a massive metal stand. A spectrum of a width equal to the length of the thermo-electric pile being cast at the proper elevation on the screen, by turning the handle of the slider the vertical face of the pile can be caused to traverse the colours, and also the spaces right and left of them.

To produce a steady spectrum of the electric light, I employed the regulator devised by M. FOUCAULT and constructed by DUBOSCQ, the constancy of which is admirable. A complete rock-salt train was constructed for me by Mr. BECKER, and arranged in the following manner. In the front orifice of the camera which surrounds the electric lamp was placed a lens of transparent rock-salt, intended to reduce to parallelism the divergent rays proceeding from the carbon-points. The parallel beam was permitted to pass through a narrow slit, in front of which was placed another rock-salt lens, the position of this lens being so arranged that a sharply defined image* of the slit was obtained at a distance beyond it equal to that at which the spectrum was to be formed. Immediately behind this lens was placed a pure rock-salt prism (sometimes two of them). The beam was thus decomposed, a brilliant horizontal spectrum being cast upon the screen which bore the thermo-electric pile. By turning the handle already referred to, the face of the pile could be caused to traverse the spectrum, an extremely narrow band of light or radiant heat falling upon it at each point of its march†. A sensitive galvanometer was connected with the pile, and from its deflection the heating-power of every part of the spectrum, visible and invisible, was determined.

Two modes of moving the instrument were practised. In the first the face of the pile was brought up to the violet end of the spectrum, where the heat was insensible, and then moved through the colours to the red, then past the red up to the position of maximum heat, and afterwards beyond this position until the heat of the invisible spectrum gradually faded away. The following Table contains a series of measurements executed in this manner. The motion of the pile is measured by turns of its handle, every turn corresponding to the shifting of the face of the instrument through a space of one millimetre, or $\frac{1}{25}$th of an inch. At the beginning, where the increment of heat was slow and gradual, the readings were taken at every two turns of the handle; on quitting the red, where the heat suddenly increases, the intervals were only half a turn, while near the maximum, where the changes were most sudden, the intervals were reduced to a quarter of a turn, which corresponded to a translation of the pile through $\frac{1}{100}$th of an inch. Intervals of one and of two turns were afterwards resumed until the heating-power ceased to be distinct. At every halting-place the deflection of the needle was noted, the value of the deflection, referred to the first degree as unit, being placed

* The width of the image was about 0·1 of an inch.

† The width of the linear pile was 0·03 of an inch.

in the first column of figures in the Table. It was found convenient to call the maximum effect in each series of experiments 100; the second column of figures, obtained by multiplying the first by the constant factor 1·37, expresses the heat of all the parts of the spectrum with reference to this maximum.

TABLE I.—Distribution of Heat in Spectrum of Electric Light.

Movement of pile.	Value of deflection.	Calorific intensity, in 100ths of the maximum.
Before starting (pile in the blue) . .	0·0	0·0
Two turns forward (green entered) .	1·5	2·0
"	3·5	4·8
"	5·5	7·5
" (red entered) . .	15·5	21·0
" (extreme red) . .	32·6	44·6
Half turn forward	44·0	60·0
"	54·0	74
"	62·0	85
"	70·0	95·8
"	72·5	99
Quarter turn forward, *maximum* . .	73·0	100·0
"	70·8	97·0
Half turn forward	57·0	78·0
"	45·5	62·0
"	32·6	44·5
"	26·0	35·6
Two turns forward	10·5	14·4
"	6·5	9
"	5·0	6·8
"	3·5	5
"	2·5	3·4
"	1·7	2·3
"	1·3	1·8

Here, as before stated, we begin in the blue, and pass first through the visible spectrum. Quitting this at the place marked "(extreme red)," we enter the invisible calorific spectrum and reach the position of maximum heat, from which, onwards, the thermal power falls till it practically disappears.

In other observations the pile was first brought up to the position of maximum heat, and moved thence to the extremity of the spectrum in one direction. It was then brought back to the maximum, and moved to the extremity in the other direction. There was generally a small difference between the two maxima, arising, no doubt, from some slight alteration of the electric light during the period which intervened

between the two observations. The following Table contains the record of a series of such measurements. As in the last case, the motion of the pile is measured by turns of the handle, and the values of the deflections are given with reference to a maximum of 100.

TABLE II.—Distribution of Heat in Spectrum of Electric Light.

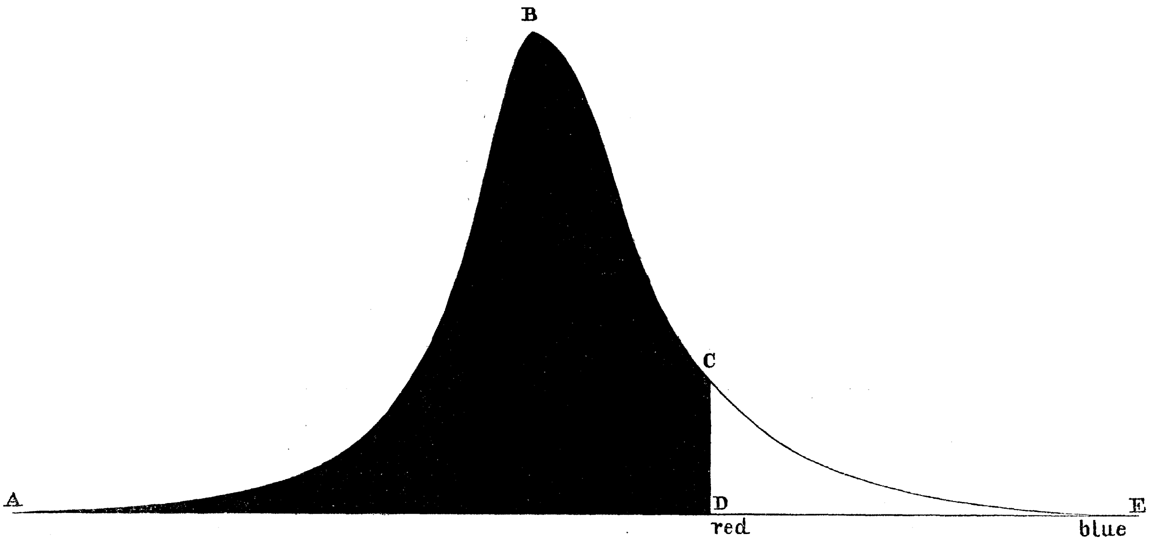
Movement of pile.	Calorific intensity, in 100ths of the maximum.
Maximum	100
One turn *towards* visible spectrum	94·4
,, ,,	65·5
,, ,,	42·6
,, ,, (extreme red)	28·3
,, ,,	20·0
,, ,,	14·8
,, ,,	11·1
Two turns in the same direction (green entered)	7·4
,, ,,	4·6
,, ,,	2·0
,, ,, (pile in blue)	0·9
Pile brought back to maximum.	
Maximum	100·0
One turn *from* visible spectrum	67·1
,, ,,	41·0
,, ,,	23·0
,, ,,	13·0
,, ,,	9·4
Two turns	5·0
,,	3·4
,,	0·0

More than a dozen series of such measurements were executed, each series giving its own curve. On superposing the different curves, however, a very close agreement was found to exist between them. The annexed curve (fig. 3), which is the mean of several, expresses, with a close approximation to accuracy, the distribution of heat in the spectrum of the electric light from fifty cells of GROVE. The space A B C D represents the invisible, while C D E represents the visible radiation. We here see the gradual augmentation of thermal power, from the blue end of the spectrum to the red. But in the region of dark rays beyond the red the curve shoots suddenly upwards in a steep and massive peak, which quite dwarfs by its magnitude the portion of the diagram representing the visible radiation*.

* How are we to picture the vibrating atoms which produce the different wave-lengths of the spectrum?

The sun's rays before reaching the earth have to pass through our atmosphere, where they encounter the atmospheric aqueous vapour, which exercises a powerful absorption on the invisible calorific rays. From this, apart from other considerations, it would follow that the ratio of the invisible to the visible radiation in the case of the sun must be less than in the case of the electric light. Experiment, we see, justifies this conclusion; for, whereas fig. 2 shows the invisible radiation of the sun to be about twice the visible, fig. 3 shows the invisible radiation of the electric light to be nearly eight times the visible. If we cause the beam from the electric lamp to pass through a layer of water of suitable thickness, we place its radiation in approximately the same condition as that of the sun; and on decomposing the beam after it has been thus sifted, we obtain a distribution of heat closely resembling that observed in the solar spectrum.

Fig. 3.



Spectrum of electric light.

Does the infinity of the latter, between the extreme ends of the spectrum, answer to an infinity of atoms each oscillating at a single rate? or are we not to figure the atoms as virtually capable of oscillating at different rates at the same time? When a sound and its octave are propagated through the same mass of air, the resultant motion of the air is the algebraic sum of the two separate motions impressed upon it. The ear decomposes this motion into its two components (HELMHOLTZ, Ton-Empfindungen, p. 54); still we cannot here figure certain particles of the air occupied in the propagation of the one sound, and certain other particles in the propagation of the other. May not what is true of the air be true of the ether? and may not, further, a single atom, controlled and jostled as it is in solid bodies by its neighbours, be able to impress upon the ether a motion equivalent to the sum of the motions of several atoms each oscillating at one rate?

It is perhaps worthy of remark, that there appears to be a definite rate of vibration for all solid bodies having the same temperature, at which the *vis viva* of their atoms is a maximum. If, instead of the electric light, we examine the lime-light, or a platinum wire raised to incandescence by an electric current, we find the apex of the curve of distribution (B, fig. 3) corresponding throughout to very nearly, if not exactly, the same refrangibility. There seems, therefore, to exist one special rate at which the atoms of heated solids oscillate with greater energy than at any other rate—a non-visual period, which lies about as far from the extreme red of the spectrum on the invisible side as the commencement of the green on the visible one.

The curve representing the distribution of heat in the electric spectrum falls most steeply on that side of the maximum which is most distant from the red. On both sides, however, we have a *continuous* falling off. I have had numerous experiments made to ascertain whether there is any interruption of continuity in the calorific spectrum; but all the measurements hitherto executed with artificial sources reveal a gradual and continuous augmentation of heat from the point where it first becomes sensible up to the maximum. Sir JOHN HERSCHEL has shown that this is not the case with the radiation from the sun when analyzed by a flint-glass prism. Permitting the solar spectrum to fall upon a sheet of blackened paper, over which had been spread a wash of alcohol, this eminent philosopher determined by its drying-power the heating-power of the spectrum. He found that the wet surface dried in a series of spots representing thermal maxima separated from each other by spaces of comparatively feeble calorific intensity. No such maxima and minima were observed in the spectrum of the electric light, nor in the spectrum of a platinum wire raised to a white heat by a voltaic current. Prisms and lenses of rock-salt, of crown glass, and of flint glass were employed in these cases. In subsequent experiments the beam intended for analysis was caused to pass through layers of water and other liquids of various thicknesses. Gases and vapours of various kinds were also introduced into the path of the beam. In all cases there was a general lowering of the calorific power, but the descent of the curve on both sides of the maximum was unbroken*.

§ 3.

The rays from an obscure source cannot compete in point of intensity with the obscure rays of a luminous source. No body heated under incandescence could emit rays of an intensity comparable to those of the maximum region of the electric spectrum. If, therefore, we wish to produce intense calorific effects by invisible rays, we must choose those emitted by an intensely luminous source. The question then arises, how are the invisible calorific rays to be isolated from the visible ones. The interposition of an opaque screen suffices to cut off the visible spectrum of the electric light, and leaves us the invisible calorific rays to operate upon at our pleasure. Sir WILLIAM HERSCHEL experimented thus when he sought, by concentrating them, to render the invisible rays of the sun visible. But to form a spectrum in which the invisible rays shall be completely separated from the visible ones, a narrow slit or a small aperture is necessary; and this circumstance renders the amount of heat separable by prismatic analysis very limited. If we wish to ascertain what the intensely concentrated invisible rays can accomplish, we must devise some other mode of detaching them from their visible companions. We must, in fact, discover a substance which shall filter the composite radiation of a luminous source by stopping the visible rays and allowing the invisible ones free transmission.

Could we obtain a *black* elementary body thoroughly homogeneous, and with all its

* At a future day I hope to subject this question to a more severe examination.

parts in perfect optical contact, experiments already published would lead me to expect that such a body would form an effectual filter for the radiation of the sun or of the electric light. While cutting off the visible radiation, the black element would, I imagine, allow the invisible to pass. Carbon in the state of soot is black, but its parts are not optically continuous. In black glass the continuity is far more perfect, and hence the result established by MELLONI, that black glass possesses a considerable power of transmission. Gold in ruby glass, or in the state of jelly prepared by Mr. FARADAY, is exceedingly transparent to the invisible calorific rays, but it is not black enough to quench entirely the visible ones. The densely brown liquid bromine is better suited to our purpose; for, in thicknesses sufficient to quench the light of our brightest flames, this element displays extraordinary diathermancy. Iodine cannot be applied in the solid condition, but it dissolves freely in various liquids, the solution in some cases being intensely dark. Here, however, the action of the element may be masked by that of its solvent. Iodine, for example, dissolves freely in alcohol; but alcohol is so destructive of the extra-red rays, that it would be entirely unfit for experiments the object of which is to retain these rays while quenching the visible ones. The same remark applies in a greater or less degree to many other solvents of iodine.

The deportment of bisulphide of carbon, both as a vapour and a liquid, suggests the thought that it would form a most suitable solvent. It is extremely diathermic, and there is hardly another substance able to hold so large a quantity of iodine in solution. Experiments already recorded prove that, of the rays emitted by a red-hot platinum spiral, 94·5 per cent. is transmitted by a layer of the liquid 0·02 of an inch in thickness, the transmission through layers 0·07 and 0·27 of an inch thick being 87·5 and 82·5 respectively*. The following experiment with a layer of far greater thickness exhibits the deportment of the transparent bisulphide towards the more intense radiation of the electric light. A cylindrical cell, 2 inches in length and 2·8 inches in diameter, with its ends stopped by plates of perfectly transparent rock-salt, was placed empty in front of an electric lamp; the radiation from the lamp, after having crossed the cell, fell upon a thermo-electric pile, and produced a deflection of

$$73^\circ.$$

Leaving the cell undisturbed, the transparent bisulphide of carbon was poured into it: the deflection fell to

$$72^\circ.$$

A repetition of the experiment gave the following results:—

	Deflection.
Through empty cell	74°
Through bisulphide	73

Taking the values of these deflections from a Table of calibration and calculating

* Philosophical Transactions, vol. cliv. p. 333; Philosophical Magazine, Ser. 4. vol. xxviii. p. 446.

the transmission, that through the empty cell being 100, we obtain the following results:—

	Transmission.
For the first experiment	94·9
For the second experiment	94·6
Mean	94·8

Hence the introduction of the bisulphide lowers the transmission only from 100 to 94·8*.

A *perfect* solvent of the iodine would be perfectly neutral to the total radiation; and the bisulphide of carbon is shown by the foregoing experiment to approach tolerably near perfection. We have in it a body capable of transmitting with little loss the total radiation of the electric light. Our object is now to filter this total, by the introduction into the bisulphide of a substance competent to quench the visible and transmit the invisible rays. Iodine does this with marvellous sharpness. In a short paper "On Luminous and Obscure Radiation," published in the Philosophical Magazine for November 1864, the diathermancy of this substance is illustrated by the following Table:—

Table III.—Radiation through dissolved Iodine.

Source.	Transmission.
Dark spiral of platinum wire	100
Lampblack at 212° Fahr.	100
Red-hot platinum spiral	100
Hydrogen-flame	100
Oil-flame	97
Gas-flame	96
White-hot spiral	95·4
Electric light, battery of 50 cells	90

These experiments were made in the following way:—A rock-salt cell was first filled with the transparent bisulphide, and the quantity of heat transmitted by the pure liquid to the pile was determined. The same cell was afterwards filled with the opaque solution, the transmission through which was also determined. Calling the transmission through the transparent liquid 100, the foregoing Table gives the transmission through the opaque. The results, it is plain, refer solely to the iodine dissolved in the bisulphide,—the transmission 100, for example, indicating, not that the solution itself, but that the body dissolved is, within the limits of error, perfectly diathermic to the radiation from the first four sources.

The layer of liquid employed in these last experiments was not sufficiently thick to quench utterly the luminous radiation from the electric lamp. A cell was therefore

* The partial destruction of the reflexion from the sides of the cell by the introduction of the bisulphide is not here taken into account.

constructed whose parallel faces were 2·3 inches apart, and which, when filled with the solution of iodine, allowed no trace of the most highly concentrated luminous beam to pass through it. Five pairs of experiments executed with this cell yielded the following results:—

Radiation from Electric Light; battery 40 cells.

	Deflection.
Through transparent bisulphide	47°·0; 46°·0
Through opaque solution	42·3; 43·5
Through transparent bisulphide	44·0; 43·7
Through opaque solution	41·2; 40·0
Through transparent bisulphide	42·0; 43·0

Calling the transmission through the transparent liquid 100, and taking the mean of all these determinations, the transmission through the opaque solution is found by calculation to be 86·8. An absorption of 13·2 per cent. is therefore to be set down to the iodine. This was the result with a battery of forty cells; subsequent experiments with a battery of fifty cells made the transmission 89 and the absorption 11.

Considering the transparency of the iodine for heat emitted by all sources heated up to incandescence, as exhibited in Table III., it may be inferred that the above absorption of 11 per cent. represents the calorific intensity of the *luminous rays* alone. By the method of filtering, therefore, we make the invisible radiation of the electric light eight times the visible. Computing, by means of a proper scale, the area of the spaces A B C D, C D E (fig. 3), the former, which represents the invisible emission, is found to be 7·7 times the latter. Prismatic analysis, therefore, and the method of filtering yield almost exactly the same result.

§ 4.

In the combination of bisulphide of carbon and iodine we find a means of filtering the composite radiation from any luminous source. The solvent is practically transparent, while the dissolved iodine cuts off every visible ray, its absorptive power ceasing with extraordinary suddenness at the extreme red of the spectrum. Doubtless the absorption extends a little way beyond the red, and with a very great thickness of solution the absorption of the extra-red rays might become very sensible. But the solution may be employed in layers which, while competent to intercept every trace of light, allow the invisible calorific rays to pass with scarcely sensible diminution.

The *ray-filter* here described was first publicly employed in the early part of 1862*. Concentrating by large glass lenses the radiation of the electric lamp, I cut off the visible portion of the radiation by the solution of iodine, and thus formed invisible foci of an intensity at that time unparalleled. In the autumn of 1864 similar experiments were executed with rock-salt lenses and with mirrors. The paper "On Luminous and Obscure Radiation," already referred to, contains an account of various effects of com-

* Philosophical Transactions, 1862, p. 67, note.

bustion and fusion which were then obtained with the invisible rays of the electric light and of the sun*.

From the setting of paper on fire, and the fusion of non-refractory metals, to the rendering of refractory bodies incandescent, the step was immediate. To avoid waste by conduction, it was necessary to employ the metals in plates as thin as possible. A few preliminary experiments with platinum foil, which resulted in failure, raised the question whether, even with the *total radiation* of the electric light, it would be possible to obtain incandescence without combustion. Abandoning the use of lenses altogether, I caused a thin leaf of platinum to approach the ignited coal points. It was observed by myself from behind, while my assistant stood beside the lamp, and, looking through a dark glass, observed the distance between the platinum foil and the electric light. At half an inch from the carbon points the metal became red-hot. The problem now was to obtain, at a greater distance, a focus which should possess a heating-power equal to that of the direct rays at a distance of half an inch.

In the first attempt the direct rays were utilized as much as possible. A piece of platinum foil was placed at a distance of an inch from the carbon points, there receiving the direct radiation. The rays emitted *backwards* from the points were at the same time converged by a small mirror upon the foil, and were found more than sufficient to compensate for the diminution of intensity due to the withdrawal of the foil to the distance of an inch. By the same method incandescence was subsequently obtained when the foil was removed two, and three, inches from the carbon points.

The last-mentioned distance allowed me to introduce between the focus and the source of rays a cell containing the solution of iodine. The transmitted obscure rays were found of sufficient power to inflame paper, or to raise platinum foil to incandescence.

These experiments, however, were not unattended with danger. The bisulphide of

* To the experiments there described the following may be added, as made at the time. A glass globe, $3\frac{3}{4}$ inches in diameter, was filled with the opaque solution, and placed in front of the electric light. An intense focus of invisible rays was formed immediately beyond the globe. Black paper held in this focus was pierced, a burning ring being produced. A second spherical flask, 9 inches in diameter, was filled with the solution and employed as a lens. The effects, however, were less powerful than those obtained with the smaller flask.

Two plano-convex lenses of rock-salt, 3 inches in diameter, were placed with their flat surfaces opposite, but separated from each other by a brass ring $\frac{3}{8}$ths of an inch thick. The space between the plates was filled with the solution, and thus an opaque lens was formed. Paper was fired by this lens. In none of these cases, however, could the paper be caused to blaze. Hollow plano-convex lenses filled with the solution were not effective, the focal length of those at my disposal being too great.

Mr. Mayall was so extremely obliging as to transfer his great photographic camera from Brighton to London, for the purpose of enabling me to operate with the fine glass lens, 20 inches in diameter, which belonged to it: the result was not successful. It will, however, be subsequently shown that both the hollow lens and the glass lens are effective when, instead of the divergent rays of the electric lamp, we employ the parallel rays of the sun.

carbon is an extremely inflammable substance; and on the 2nd of November, while employing a very powerful battery and intensely heated carbon points, the solution took fire, and instantly enveloped the electric lamp and all its appurtenances in flame. The precaution, however, had been taken of placing the entire apparatus in a flat vessel containing water, into which the flaming mass was summarily turned. The bisulphide of carbon being heavier than the water, sank to the bottom, so that the flames were speedily extinguished. Similar accidents occurred twice subsequently.

Such occurrences caused me to seek earnestly for a substitute for the bisulphide. Pure chloroform, though not so diathermic, transmits the obscure rays pretty copiously, and it freely dissolves iodine. In layers of the thickness employed, however, the solution was not sufficiently opaque; and in consequence of its absorptive power, but comparatively feeble effects were obtained with it. The same remark applies to the iodides of methyl and ethyl, to benzol, acetic ether, and other substances. They all dissolve iodine, but they enfeeble the results by their action on the extra-red rays.

I had special cells constructed for bromine and chloride of sulphur; neither of these substances is inflammable, but they are both intensely corrosive, and their action upon the lungs and eyes is so irritating as to render their employment impracticable. With both of these liquids powerful effects were obtained; still their diathermancy, though very high, did not come up to that of the dissolved iodine. Bichloride of carbon would be invaluable if its solvent power were equal to that of the bisulphide. It is not at all inflammable, and its own diathermancy appears to excel that of the bisulphide. But in reasonable thicknesses the iodine which it can dissolve is not sufficient to render the solution perfectly opaque. The solution forms a purple colour of indescribable beauty. Though unsuited to strict crucial experiments on dark rays, this filter may be employed with good effect in class experiments.

Thus foiled in my attempts to obtain a solvent equally good and less dangerous than the bisulphide of carbon, I sought to reduce to a minimum the danger of employing this substance. At an early period of the investigation I had constructed a tin camera, within which were placed both the lamp and its mirror. Through an aperture in front, $2\frac{3}{4}$ inches wide, the cone of reflected rays issued, forming a focus outside the camera. Underneath this aperture was riveted a stage, on which the solution of iodine rested, closing the aperture and cutting off all the light. In the first experiments nothing intervened between the cell and the carbon points; but the peril of thus exposing the bisulphide caused me to make the following improvements. First, a perfectly transparent plate of rock-salt, secured in a proper cap, was employed to close the aperture; and by it all direct communication between the solution and the incandescent carbons was cut off. The camera itself, however, became quickly heated by the intense radiation falling upon it, and the cell containing the solution was liable to be warmed both by the camera and by the luminous rays which it absorbed. The aperture above referred to was therefore surrounded by an annular space, about $2\frac{1}{2}$ inches wide and a

quarter of an inch deep, through which cold water was caused to circulate. The cell containing the solution was moreover surrounded by a jacket, and the current, having completed its course round the aperture, passed round the solution. Thus the apparatus was kept cold. The neck of the cell was stopped by a closely-fitting cork; through this passed a piece of glass tubing, which, when the cell was placed upon its stage, ended at a considerable distance from the focus of the mirror. Experiments on combustion might therefore be carried on at the focus without fear of igniting the small amount of vapour which even under the improved conditions might escape from the bisulphide of carbon. The arrangement will be at once understood by reference to Plate I. figs. 4 *a* & *b*, which show the camera, lamp, and filter both from the side and from the front. $x\,y$ is the mirror from which the reflected cone of rays passes, first through the rock-salt window (unshaded), and afterwards through the iodine filter $m\,n$. The rays converge to the focus k, where they would form an invisible image of the lower carbon point; the image of the upper would be thrown below k; and both images spring vividly forth when a leaf of platinized platinum is exposed at the focus. At $s\,s$ (Plate I. fig. 4 *a*) is shown, in section, the annular space in which the cold water circulates. Fig. 4 *b* (Plate I.) shows the manner in which the water enters this space and passes from it to the jacket surrounding the iodine-cell m.

With this arrangement, and a battery of fifty cells, the following results were obtained:—

A piece of silver-leaf, fastened to a wire ring and tarnished by exposure to the fumes of sulphide of ammonium, being held in the dark focus, the film flashed out occasionally into vivid redness.

Copper-leaf tarnished in a similar manner, when placed at the focus, was raised to redness.

A piece of platinized platinum foil was supported in an exhausted receiver, the vessel being so placed that the focus fell upon the platinum. The heat of the focus was instantly converted into light, a clearly defined and inverted image of the points being stamped upon the metal. Fig. 5 (Plate I.) represents the thermograph of the carbons.

Blackened paper was now substituted for the platinum in the exhausted receiver. Placed at the focus of invisible rays, the paper was instantly pierced, a cloud of smoke was poured through the opening, and fell like a cascade to the bottom of the receiver. The paper seemed to burn without incandescence. Here also a thermograph of the coal points was stamped out. When black paper is placed at the focus, where the thermal image is well defined, it is always pierced in two points, answering to the images of the two carbons. The superior heat of the positive carbon is shown by the fact that its image first pierces the paper; it burns out a large space, and shows its peculiarly crater-like top, while the negative carbon usually pierces a small hole.

Paper reddened by the iodide of mercury had its colour discharged at the places on which the invisible image of the coal points fell upon it.

Disks of paper reduced to carbon by different processes were raised to brilliant incandescence, both in the air and in the exhausted receiver.

In these earlier experiments I made use of apparatus which had been constructed for other purposes. The mirror, for example, was detached from a DUBOSCQ's camera, first silvered at the back, but afterwards silvered in front. The cell employed for the iodine solution was also that which usually accompanies DUBOSCQ's lamp, being intended by its maker for a solution of alum. Its sides are of good white glass, the width from side to side being 1·2 inch.

§ 5.

A point of considerable theoretic importance was involved in these experiments. In his excellent researches on fluorescence, Professor STOKES had invariably found the refrangibility of the incident light to be *lowered.* This rule was so constant as almost to enforce the conviction that it was a law of nature. But if the rays which in the foregoing experiments raised platinum and gold and silver to a red heat were wholly extra-red, the rendering visible of the metallic films would be an instance of *raised* refrangibility.

And here I thought it desirable to make sure that no trace of the visible radiation passed through the solution, and also that the invisible radiation was exclusively extra-red.

This latter condition might seem to be unnecessary, because the calorific action of the extra-violet rays is so exceedingly feeble (in fact so immeasurably small) that, even supposing them to reach the platinum, their heating-power would be an utterly vanishing quantity. Still mechanical considerations rendered the exclusion of *all* rays, of a higher refrangibility than those generated at the focus, necessary to the rigid solution of the problem. Hence, though the iodine employed in the foregoing experiments was sufficient to cut off the light of the sun at noon, I wished to submit its opacity to a severer test. The following experiments were accordingly executed.

A piece of thick black paper, mounted on a retort-ring, was caused gradually to approach the focus of obscure rays. The position of the focus was announced by the piercing of the paper; the combustion being quenched, the retort-ring was moved slightly nearer to the lamp, so that the converged beam passed through the burnt aperture, the focus falling about $\frac{1}{2}$ an inch beyond. A bit of blackened platinum held immediately behind the aperture was raised to redness over a considerable space. The platinum was then moved to and fro until the maximum degree of incandescence was obtained, the point where this occurred being accurately marked. A cell containing a solution of alum was then placed between the diaphragm of black paper and the iodine-cell. The alum solution diminished materially the invisible radiation, but it was without sensible influence on such visible rays as the concentrated beam contained. All stray light issuing from the crevices in the lamp had been previously cut off, the daylight also being excluded from the room. The eye was then brought on a level with the aperture and slowly approximated to it, until the point which marked the focus was

reached. A singular appearance presented itself. The incandescent coke points of the lamp were seen perfectly black, projected on a deep-red ground. When the points were moved up and down, their black images moved also. When brought into contact, a white space was seen at the extremities of the points, appearing to separate them. The points were seen erect. By careful observation the whole of the points could be seen, and even the holders which supported them. The black appearance of the incandescent portion of the points could of course only be relative; they intercepted more of the light reflected from the mirror behind than they could make good by their direct emission.

The solution of iodine, 1·2 inch in thickness, proving unequal to the severe test here applied to it, I had two other cells constructed—the one with transparent rock-salt sides, the other with glass ones. The width of the former was 2 inches, that of the latter nearly $2\frac{1}{2}$ inches. Filled with the solution of iodine, these cells were placed in succession in front of the camera, and the concentrated beam was sent through them. Determining the focus as before, and afterwards introducing the alum-cell, the eye on being brought up to the focus received no impression of light. The alum-cell was then abandoned, and the undefended eye was caused to approach the focus: the heat was intolerable, but it seemed to affect the eyelids and not the retina. An aperture somewhat larger than the pupil being made in a metal screen, the eye was placed behind it, and brought slowly and cautiously up to the focus. The whole concentrated beam here entered the pupil; but no impression of light was produced, nor was the retina sensibly affected by the heat. The eye was then withdrawn, and a plate of platinized platinum was placed in the position occupied by the retina a moment before. It instantly rose to vivid redness*. The rays which produced this incandescence were certainly invisible ones, and the failure to obtain, with the most sensitive media and in the darkest room, the slightest evidence of fluorescence at the obscure focus, proved the invisible rays to be exclusively extra-red.

When intense effects are sought after, the problem is to collect as many of the invisible rays as possible, and to concentrate them on the smallest possible space. The nearer the mirror is to the source of rays, the more of these rays will it intercept and reflect, and the nearer the focus is to the same source, the smaller will the image be. To secure proximity both of focus and mirror, the latter must be of short focal length. If a mirror of long focal length be employed, its distance from the source of rays must be considerable to bring the focus near the source, but when placed at a distance, a great number of rays escape the mirror altogether. If, on the other hand, the mirror be too deep, spherical aberration comes into play; and though a vast quantity of rays may be collected, their convergence at the focus is imperfect. To determine the best form of mirror, I had three constructed: the first is 4·1 inches in diameter and of 1·4 inch focal length; the second 7·9 inches in diameter and of 3 inches focal length; the third 9 inches in diameter, with a focal length of 6 inches. Fractures caused by imperfect annealing repeatedly occurred; but at length I was so fortunate as to obtain the three mirrors, each

* I do not recommend the repetition of these experiments.

without a flaw. The most convenient distance of the focus from the source, I find to be about 5 inches; and the position of the mirror ought to be arranged accordingly. This distance permits of the introduction of an iodine-cell of sufficient depth, while the heat at the focus is exceedingly powerful.

The isolation of the luminiferous ether from the air is strikingly illustrated by these experiments. The air at the focus may be of a freezing temperature, while the ether possesses an amount of heat competent, if absorbed, to impart to that air the temperature of flame. An air-thermometer is unaffected where platinum is raised to a white heat. Numerous experiments will suggest themselves to every one who wishes to operate upon the invisible heat-rays. The dense volumes of smoke which rise from a blackened block of wood when it is placed in the dark focus are very striking: matches are of course at once ignited, and gunpowder instantly exploded. Dry black paper held there bursts into flame. Chips of wood are also inflamed: the dry wood of a hat-box is very suitable for this experiment. When a sheet of brown paper is placed a little beyond the focus, it is first brought to vivid incandescence over a large space; the paper then yields, and the combustion propagates itself as a burning ring round the centre of ignition. Charcoal is reduced to an ember at the focus, and disks of charred paper glow with extreme vividness. Sheet lead and tin, if blackened, may be fused, while a thick cake of fusible metal is quickly pierced and melted. Blackened zinc foil placed at the focus bursts into flame; and by drawing the foil slowly through the focus, its ignition may be kept up till the whole of the foil is consumed. Magnesium wire, flattened at the end and blackened, also bursts into vivid combustion. A cigar or a tobacco-pipe may of course be instantly lighted at the dark focus. The bodies experimented on may be enclosed in glass receivers, the concentrated rays will still burn them after having crossed the glass. A small chip of wood in a jar of oxygen bursts suddenly into flame; charcoal burns, while charcoal bark throws out suddenly showers of scintillations.

§ 6.

In all these cases the body exposed to the action of the invisible rays was more or less combustible. It required to be heated more or less to initiate the attack of the atmospheric oxygen. Its vividness was in great part due to combustion, and does not furnish a conclusive proof that the refrangibility of the incident rays was elevated. This, which is the result of greatest theoretic import, is effected by exposing non-combustible bodies at the focus, or by enclosing combustible ones in a space devoid of oxygen. Both in air and *in vacuo* platinized platinum foil has been repeatedly raised to a white heat. The same result has been obtained with a sheet of charcoal or coke suspended *in vacuo*. On looking at the white-hot platinum through a prism of bisulphide of carbon, a rich and complete spectrum was obtained. All the colours, from red to violet, glowed with extreme vividness. The waves from which these colours were primarily extracted had neither the visible nor the extra-violet rays commingled with them; they were exclusively extra-red. The action of the atoms of platinum, copper, silver, and carbon upon these

rays transmutes them from heat-rays into light-rays. They impinge upon the platinum at a certain rate; they return from it at a quicker rate. Their refrangibility is thus raised, the invisible being rendered visible.

To express this transmutation of heat-rays into others of higher refrangibility, I would propose the term *calorescence*. It harmonizes well with the term "fluorescence" introduced by Professor STOKES, and is also suggestive of the character of the effects to which it is applied. The phrase "transmutation of rays," introduced by Professor CHALLIS*, covers both classes of effects.

§ 7.

In the foregoing section I have described arrangements made with a view of avoiding the danger incidental to the use of so inflammable a substance as the bisulphide of carbon. I have since thought of accomplishing this end in a simpler way, and thus facilitating the repetition of the experiments. The following arrangement (Plate I. fig. 6) may be adopted with safety.

A B C D is an outline of the camera.

$x\,y$ the silvered mirror within it.

c the carbon points of the electric light.

$o\,p$ the aperture in front of the camera, through which issues the beam reflected by the mirror $x\,y$.

Let the distance of the mirror from the carbon points be such as to render the reflected beam slightly convergent.

Fill an ordinary glass flask with the solution of iodine, and place the flask in the path of the reflected beam at a safe distance from the lamp. The flask acts as a lens and filter at the same time, the bright rays are intercepted, and the dark ones are powerfully converged. F, Plate I. fig. 6, represents such a flask; and at the focus formed a little beyond it combustion and calorescence may be produced.

The following results have been obtained with a series of flasks of different dimensions, at a distance of $3\frac{1}{2}$ feet from the carbon points.

1. With a spherical flask, $6\frac{3}{4}$ inches in diameter: platinum was raised to redness at the focus, and black paper inflamed.

2. Ordinary Florence flask, $3\frac{1}{4}$ inches in diameter: platinum raised to bright redness over a large irregular space. Near the lamp, the effects obtained with this flask were very striking.

3. Small flask, 1·8 inch in diameter, not quite spherical: platinum rendered white-hot; paper immediately inflamed.

4. A still smaller flask, 1·5 inch in diameter: effects very good; about the same as the last.

5. The bulb of a pipette: effects striking, but not quite so brilliant as with the less regularly shaped small flasks.

* Philosophical Magazine, Ser. 4. vol. xii. p. 521.

It follows as a matter of course, that where platinum is raised to whiteness, the combustion of wood, charcoal, zinc, and magnesium may also be effected.

By the arrangement here described, platinum has been raised to redness at a distance of 22 feet from the source of the rays.

The best mirror, however, scatters the rays more or less; and by this scattering, the beam at a great distance from the lamp becomes much enfeebled. The effect in free air is intensified when the beam is caused to pass through a tube polished within, which prevents the lateral waste of radiant heat. Such a tube, placed in front of the camera, is represented at A B, fig. 7, Plate I. The flask may be held against its end by the hand, or it may be permanently fixed there. With a battery of fifty cells platinum may be raised to a white heat at the focus of the flask.

Again, instead of a flask filled with the opaque solution, let a glass or rock-salt lens (L, fig. 8, Plate I.), 2·5 inches wide, and having a focal length of 3 inches, be placed in the path of the reflected beam. The rays are converged; and at their point of convergence all the effects of calorescence and combustion may be obtained.

In this case the luminous rays are to be cut off by a cell ($m\,n$) with plane glass sides; it may be placed either before or behind the lens.

Finally, the arrangement shown in Plate I. fig. 9 may be adopted. The beam reflected by the mirror within the camera is received and converged by a second mirror, $x'\,y'$. At the point of convergence, which may be several feet from the camera, all the effects hitherto described may be obtained. The light of the beam may be cut off at any convenient point of its course; but in ordinary cases the experiment is best made by employing the bichloride instead of the bisulphide of carbon, and placing the cell ($m\,n$) containing the opaque solution close to the camera. The moment the coal points are ignited, explosion, combustion, or calorescence, as the case may be, occurs at the focus.

The ordinary lamp and camera of Duboscq may be employed in these experiments. With proper mirrors, which are easily procured, a series of effects which, I venture to affirm, will interest everybody who witnesses them may, with the greatest facility, be obtained.

It is also manifest that, save for experiments made in darkness, the camera is not necessary. The mirrors and filter may be associated with the naked lamp.

I have sought to *fuse* platinum with the invisible rays of the electric light, but hitherto without success. In some experiments I have employed a large model of Foucault's lamp, which permitted me to use a battery of 100 cells. In other experiments I employed two batteries, one of 100 cells and one of 70, making use of two lamps, two mirrors, and two filters, and converging the heat of both lamps in opposite directions upon the same point. When a leaf of platinum was placed at the common focus, the converged beams struck it at opposite sides, and raised it to dazzling whiteness. I am persuaded that the metal could be fused, if the platinum black upon its surface could be retained. But this was immediately dissipated by the intense heat, and, the reflecting power of the metal coming into play, the absorption was so much lowered that fusion was not

effected. By coating the platinum with lampblack it has been brought to the verge of fusion, the incipient yielding of the mass being perfectly apparent after it had cooled. Here, however, as in the case of the platinized platinum, the absorbing substance disappears too quickly. Copper and aluminum, however, when thus treated, are speedily burnt up.

§ 8.

Thus far I have dealt exclusively with the invisible radiation of the electric light; but all solid bodies raised to incandescence emit these invisible calorific rays. The denser the incandescent body, moreover, the more powerful is its obscure radiation. We possess at the Royal Institution very dense cylinders of lime for the production of the Drummond light; and when a copious oxyhydrogen-flame is projected against one of them it shines with an intense yellowish light, while the obscure radiation is exceedingly powerful. Filtering the latter from the total emission by the solution of iodine, all the effects of combustion and calorescence described in the foregoing pages may be obtained at the focus of the invisible rays. The light obtained by projecting the oxyhydrogen-flame upon compressed magnesia, after the manner of Signor CARLEVARIS, is whiter than that emitted by our lime; but the substance being light and spongy, its obscure radiation is surpassed by that of our more solid cylinders*.

The invisible rays of the sun have also been transmuted. A concave mirror, 3 feet in diameter, was mounted on the roof of the Royal School of Mines in Jermyn Street. The focus was formed in a darkened chamber in which the platinized platinum foil was exposed. Cutting off the visible rays by the solution of iodine, feeble but distinct incandescence was there produced by the invisible rays.

A blackened tin tube (A B, fig. 10, Plate I.) with square cross section and open at one end, was furnished at the other with a plane mirror ($x y$) forming an angle of 45° with the axis of the tube. A lateral aperture ($x o$), about 2 inches square, was cut out in front of the mirror. Over this aperture was placed a leaf of platinized platinum. Turning the leaf towards the concave mirror, the concentrated sunbeams were permitted to fall upon it. In the glare of daylight it was quite impossible to see whether the platinum was incandescent or not; but placing the eye at B, the glow of the platinum could be seen by reflexion from the plane mirror. Incandescence was thus obtained at the focus of the large mirror, X Y, after the removal of the visible rays by the iodine solution, $m n$.

* The discovery of fluorescence by Professor STOKES naturally excited speculation as to the possibility of a change of refrangibility in the opposite direction. Mr. GROVE, I believe, made various experiments with a view to effect such a change; but very soon after the publication of Professor STOKES's Memoir Dr. MILLER pointed to the lime-light itself as an instance of raised refrangibility. From its inability to penetrate glass screens, he inferred that the radiation of the oxyhydrogen-flame was almost wholly extra-red, an inference the truth of which has been since established by direct prismatic analysis. The intense light produced by the oxyhydrogen-flame when projected upon lime must, he concluded, involve a change of period from slow to quick, or, in other words, a virtual elevation of refrangibility. (Elements of Chemistry, 1855, p. 210.)

To obtain a clearer sky, I had this mirror transferred to the garden of my friend Mr. LUBBOCK, near Chislehurst. The effects obtained with the total solar radiation were extraordinary. Large spaces of the platinum leaf, and even thick foil, when exposed at the focus, disappeared as if vaporized*. The handle of a pitchfork, similarly exposed, was soon burnt quite across. Paper placed at the focus burst into flame with almost explosive suddenness. The high ratio which the visible radiation of the sun bears to the invisible was strikingly manifested in these experiments. With a *total* radiation vastly inferior, the invisible rays of the electric light, or of the lime-light, raise platinum to whiteness, while, when the visible constituents of the concentrated sunbeam were intercepted, the most that could be obtained from the dark rays of the sun was a bright-red heat. The heat of the luminous rays is so great as to render it exceedingly difficult to experiment with the solution of iodine. It boiled up incessantly, exposure for two or three seconds being sufficient to raise it to ebullition. This high ratio of the luminous to the non-luminous radiation, is doubtless to be ascribed in part to the absorption of a large portion of the latter by the aqueous vapour of the air. From it, however, may also be inferred the enormous temperature of the sun.

Converging the sun's rays with a hollow lens filled with the solution of iodine, incandescence was obtained at the invisible focus of the lens on the roof of the Royal Institution.

Knowing the permeability of good glass to the solar rays, I requested Mr. MAYALL to permit me to make a few experiments with his fine photographic lens at Brighton. Though exceedingly busy at the time, he in the kindest manner abandoned to my assistant, Mr. BARRETT, the use of his apparatus for the three best hours of a bright summer's day. A red heat was obtained at the focus of the lens after the complete withdrawal of the luminous portion of the radiation.

§ 9.

Black paper has been very frequently employed in the foregoing experiments, the action of the invisible rays upon it being most energetic. This suggests that the absorption of those rays is not independent of colour. A red powder is red because of the entrance and absorption of the luminous rays of higher refrangibility than the red, and the ejection of the unabsorbed red light by reflexion at the limiting surfaces of the particles of the red body. This feebleness of absorption of the red rays extends to the rays of greater length beyond the red; and the consequence is that red paper when exposed at the focus of invisible rays is scarcely charred, when black paper bursts in a moment into flame. The following Table exhibits the condition of paper of various kinds when exposed at the dark focus of an electric light of moderate intensity.

* Concentrating the solar rays with a mirror 9 inches in diameter and of 6 inches focal length upon a leaf of platinized platinum, the metal was instantly pierced. Causing the focus to pass along the leaf, it was cut by the sunbeam, as if a sharp instrument had been drawn along it.

Paper.	Condition.
Glazed orange-coloured paper	Barely charred.
,, red- ,,	Scarcely tinged; less than the orange.
,, green- ,,	Pierced with a small burning ring.
,, blue- ,,	The same as the last.
,, black- ,,	Pierced; and immediately set ablaze.
,, white- ,,	Charred; not pierced.
Thin foreign-post	Barely charred; less than the white.
Foolscap	Still less charred; about the same as the orange.
Thin white blotting-paper	Scarcely tinged.
,, whitey-brown ,,	The same; a good deal of heat seems to get through these two last papers.
Ordinary brown ,,	Pierced immediately, a beautiful burning ring expanding on all sides.
Thick brown ,,	Pierced, not so good as the last.
Thick white sand-paper	Pierced with a burning ring.
Brown emery ,,	The same as the last.
Dead-black ,,	Pierced, and immediately set ablaze.

We have here an almost total absence of absorption on the part of the red paper. Even white absorbs more, and is consequently more easily charred. Rubbing the red iodide of mercury over paper, and exposing the reddened surface at the focus, a thermograph of the coal points is obtained, which shows itself by the discharge of the colour at the place on which the invisible image falls. Expecting that this change of colour would be immediate, I was at first surprised at the time necessary to produce it. We are here reminded of FRANKLIN'S experiments on cloths of different colours, and his conclusion that dark colours are the best absorbers. This conclusion, however, might readily be pushed too far. FRANKLIN'S colours were of a special kind, and their deportment by no means warrants a general conclusion. The invisible rays of the sun possess, according to MÜLLER, twice the energy of the visible ones. A white substance may absorb the former, while a dark substance—dark because of its absorption of the feeblest portion of the radiation—may not do so. The white powder of alum and the dark powder of iodine, exposed to the action of a source in which the invisible rays greatly surpass the visible in calorific power, exhibit a deportment at direct variance with the popular notion that dark colours are the best absorbers.

§ 10.

In conclusion, I would briefly refer to a few experiments made to determine the calorescence obtainable through glasses of various colours. In the first column of the subjoined Table the colour of the glass is given; in the second column the effect observed when a brilliant spectrum was regarded through the glass is stated; and in

the third column the appearance of a leaf of platinized platinum when placed at the focus, after the converged beam had passed through the glass, is mentioned.

Colour of glass.	Prismatic examination.	Calorescence.
Dark red	Red only transmitted	Dull white heat.
Mean red	Red only transmitted	White heat.
Light red	Yellow intercepted with greatest power	Bright white.
Yellow	All the blue end absorbed	Vivid red with bright yellow in centre.
Green	Besides the green, a dull red fringe and a blue band were transmitted	No incandescence.
Dark purple	Extreme blue and red transmitted	Vivid orange.
Mean purple	Central portion of spectrum cut out	Vivid orange.
Light purple	Dims the whole spectrum, but chiefly absorbs the green	Vivid orange.
Dark blue	Transmits the blue, a green band, and a band in the extreme red	Red heat.
Mean blue	Blue; a yellowish-green band and the extreme red transmitted	Reddish-pink heat.
Light blue	Transmits a series of bands—blue and green, a red band next orange, then a dark-red band, and finally extreme red	Pink heat, passing into red.
Another blue glass		Pink heat.
Black glass No. 1	Dims all the spectrum: white light transmitted	Barely visible red.
Black glass No. 2	Whitish-green light transmitted	Dull red.
Black glass No. 3	Deep-red light transmitted	Bright red, orange in the middle.

The extremely remarkable fact here reveals itself, that when the beam of the electric lamp is sifted by certain blue glasses, the platinum at the focus glows with a distinct pink colour. Every care was taken to avoid subjective illusion here. The pink colour was also obtained at the focus of invisible rays. Withdrawing all the glasses, and filtering the beam by a solution of iodine alone, platinum was raised nearly to whiteness at the focus. On introducing the pale-blue glass between the iodine cell and the focus, the calorescence of the platinum was greatly enfeebled—so much so, that a darkened room was necessary to bring it out in full distinctness; when seen, however, the thermograph was pink. A disk of carbonized paper being exposed at the obscure focus, rose at once to vivid whiteness when the blue glass was absent; but when present, the colour of the light emitted by the carbon was first a distinct pink; the attack of the atmospheric oxygen soon changes this colour, the combustion of the carbon extending on all sides as a white-hot circle. If subsequent experiments should confirm this result, it would

follow that there is a gap in the calorescence, the atoms of the platinum vibrating in red and blue periods, and not in intermediate ones. But I wish here to say that further experiments, which I hope shortly to make, are necessary to satisfy my own mind as to the cause of this phenomenon.

The incandescent thermograph of the coal points being obtained, a very light-red glass introduced between the opaque solution and the platinum reduced the thermograph both in size and brilliancy. A second red glass, of deeper colour, rendered the thermograph still smaller and feebler. A dark-red glass reduced it still more—the visible surface being in this case extremely minute, and the heat a dull red merely. When, instead of the coloured glass, a sheet of pure-white glass was introduced, the image of the coal points stamped upon the platinum foil was scarcely diminished in brilliancy. A thick piece of glass of deep ruby-red proved equally transparent; its introduction scarcely changed the vividness of the thermograph. The colouring-matter in this instance was the *element* gold, not the compound suboxide of copper employed in the other red glasses. Many specimens of gold jelly, prepared by Mr. Faraday for his investigation of the colours of gold, though of a depth approaching to absolute blackness, showed themselves eminently transparent to the obscure heat-rays; their introduction scarcely dimmed the brilliancy of the thermograph. Hence it would appear that even the metals themselves, in certain states of aggregation, share that high diathermic power which the elementary metalloids have been found to display.

I have just said that a sheet of pure-white glass, when interposed in the path of the condensed invisible beam, scarcely dimmed the brilliancy of the thermograph. The intense calorific rays of the electric light pass through such glass with freedom. We here come to a point of considerable practical importance to meteorologists. When such pure-white glass has carbon mixed with it when in a molten condition, the resulting black glass is still eminently transparent to those invisible heat-rays which constitute the greater part of the sun's radiation. I have pieces of glass, to all appearance black, which transmit 63 per cent. of the total heat of the electric light; and there is not the slightest doubt that, in thicknesses sufficient to quench entirely the light of the sun, such glass would transmit a large portion of his invisible heat-rays. This is the glass often, if not uniformly, employed in the construction of our black-bulb thermometers, under the impression that the blackening secures the entire absorption of the solar rays. This conclusion is fallacious, and the instruments are correspondingly defective. A large portion of the sun's rays pass through such black glass, impinge upon the mercury within the bulb, and are ejected by reflexion. Such rays contribute nothing to the heating of the thermometer.

When a sheet of common window-glass, apparently transparent, was placed between the iodine solution and the platinum leaf at the focus, the thermograph was more dimmed than by the black glass last referred to. The window-glass here employed, when looked at edgeways, was green; and this experiment proves how powerfully this green colouring-matter, even in infinitesimal quantity, absorbs the invisible heat-rays.

Perfect imperviousness might doubtless be secured by augmenting the quantity of green colouring-matter. It is with glass of this description that the carbon should be mixed in the construction of black-bulb thermometers; on entering such glass the solar rays would be entirely absorbed, and greater differences than those now observed would probably be found to exist between the black-bulb and the ordinary thermometer.

In conclusion, it gives me pleasure to mention the intelligence and skill displayed by my assistant, Mr. Barrett, in executing the numerous experiments committed to his care during the progress of this investigation.

Fig. 4 b.

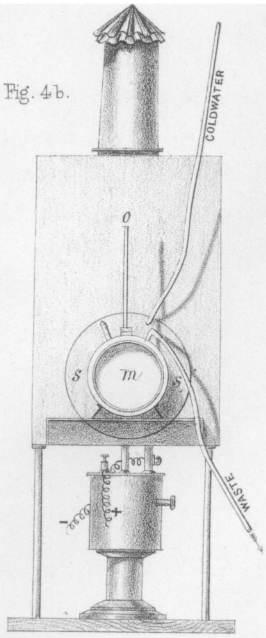


Fig. 4 a.

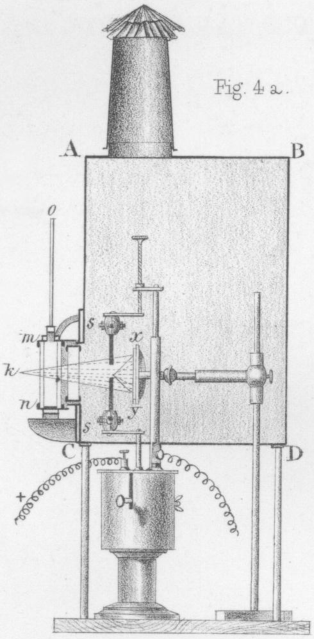


Fig. 5.

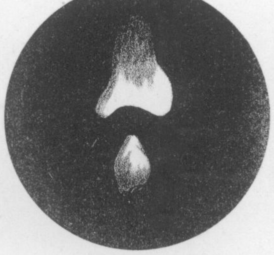


Fig. 6.

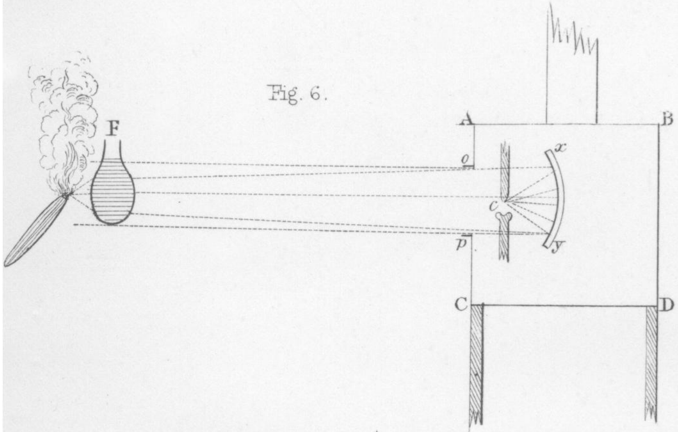


Fig. 7.

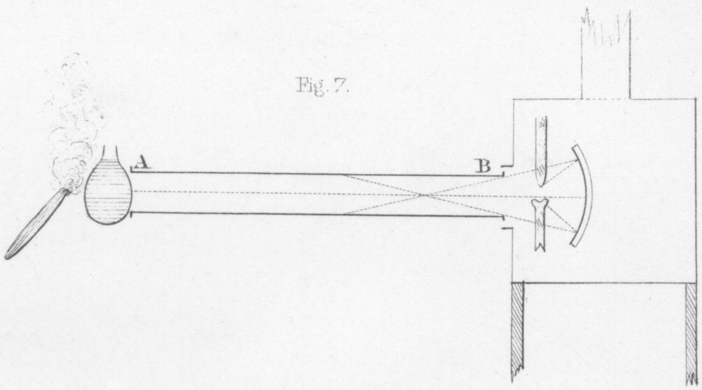


Fig. 8.

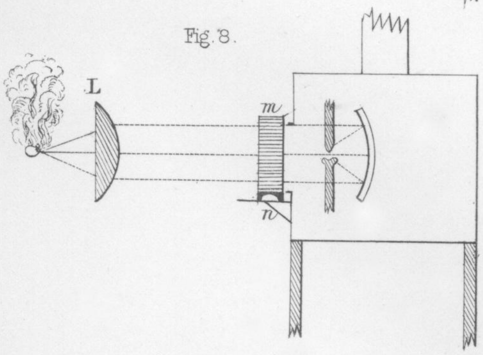


Fig. 9.

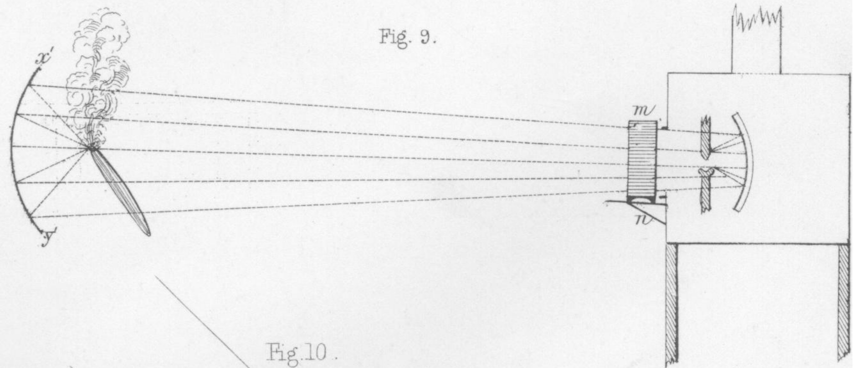
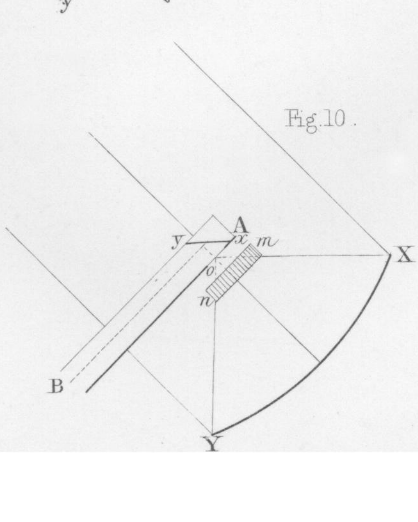


Fig. 10.



J. Basire lith.